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| Vienna to Gloggnitz . . | 47 miles. |
| Gloggnitz to Murzzuschlag . | 26 ,, |
| Murzzuschlag to Laibach . | 200 ,, |
| Laibach to Trieste . . . | $89\frac{1}{2}$ ,, |
| | $362\frac{1}{2}$ miles. |

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| „ | Breitenstein to Semmering | 1 in 54 „ | 3·574 „ |
| „ | Semmering to Spital . | 1 in 50 „ | 4·454 „ |
| „ | Spital to Murzzuschlag . | 1 in 50 „ | 3·856 „ |

The average gradient from Payerbach to Semmering is 1 in 47, for 13·210 miles, and from Semmering to Murzzuschlag, 1 in 50, for 8·310 miles.

| | |
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The following is a brief description of the type of engine, now in use upon the Semmering:—The fire-box surface is 75 square feet, with 189 tubes of 2 inches diameter and 15 feet 7 inches in length, giving a tubular heating surface of 1,585 square feet. The total heating surface is thus 1,660 square feet, which gives, as will afterwards appear, $5\frac{1}{2}$ square feet, per effective horse power. The grate area is 12·6 square feet, or $\frac{1}{130}$th of the heating surface. The total weight of the engine, filled and loaded, is $55\frac{1}{4}$ tons. This load is thus distributed:—$13\frac{1}{2}$ tons on the leading-wheels, $12\frac{1}{4}$ tons on the middle wheels; and 13 tons on the driving-wheels; or $38\frac{3}{4}$ tons on the three pairs of coupled wheels. There were also $16\frac{1}{2}$ tons equally distributed on the two trailing-wheels, which weight was, at first, detached from the other, but was subsequently brought to assist the former, by means of axles, with toothed wheels, keyed on them. The diameter of the cylinders is 18·7 inches, the stroke is 25 inches, and the diameter of the wheels is 3 feet $7\frac{3}{4}$ inches. The last two axles are held in a peculiar description of 'bogie,' which also contains the driver's platform and the fuel. The water is carried in tanks at each side of the boiler, which is elliptical in section, and on a platform, supported by brackets, bolted on the framing of the six driving-wheels: by this arrangement, the whole weight of the engine and of the water is used to insure adhesion to the rails. The cylinders are outside the framings, with the valve-gearing on the outer sides; the eccentrics are carried on a kind of overhanging crank.

The Austrian Government required, that any engine, to be considered fit for the Semmering traffic, should be able to convey a load of 110 tons, (engine and tender not included,) over the mountain, at a speed of 10 miles per hour; and that it should not consume more than 144 cubic feet of dry wood, per hour. Now the weight of M. Engerth's engine is $55\frac{1}{4}$ tons. To find, therefore, the duty required of the locomotive, in order to convey a load of 160 tons, (engine included,) up an incline of 1 in 40, and

round curves of $9\frac{1}{2}$ chains radius, at a minimum speed of 10 miles per hour, the following conditions must be fulfilled:—

1st. The necessary power must be produced equal to 69, (the resistance in lbs. per ton,) multiplied by 160, (the number of tons conveyed,) multiplied by 880, (the rate in feet per minute,) $= \frac{10 \text{ miles } 5{,}280 \text{ feet}}{60 \text{ minutes}} = 10$ miles per hour. This gives

$$\frac{69 \times 160 \times 880}{33{,}000} = 294 \cdot 4$$

to express in horse power, the work done.

2nd. The tractive force at the rails, at any moment, must be equal to the resistance offered by the load, or to $69 \times 160 = 11{,}040$ lbs.

3rd. The load on the driving-wheels on the Semmering, must be, at least, eight times the tractive force, since in bad weather, friction sometimes fell below this; consequently, the load on the driving-wheels, ought to be $11{,}040 \times 8 = 88{,}320$ lbs., or nearly 40 tons. Again, from the sharp curves of the line, it was found necessary, that the distance between axles, intended to remain parallel, should not exceed 8 feet. There seem, therefore, to have been no existing engines, which could have satisfied all these conditions. Thus, Mr. Gooch's saddle-tank engine has wheels of 5 feet diameter, and the weight on them is only 21 tons. All the class of six-wheeled goods engines have the axles too far apart. A simple solution would have been, to have used two ordinary engines together, as on the Giovi Incline; but this was contrary to the wishes of the Government, who desired to reduce the number of drivers and also of engines; thus the system introduced by M. Engerth, was, to say the least, a forced solution of the problem.

The following are some particulars, before the tooth-wheel gear was added, to couple the trailing to the driving-wheels of the engine:—

Gradient 1 in 40—Eichberg to Klamm;

| | |
|---|---|
| Weight of dead load . . . . | = 110 tons. |
| Weight of engine and tender . . | = $55\frac{1}{4}$ „ |
| Water evaporated per hour, (stoppages not included,) . . . . | = 255 cubic feet. |
| Wood consumed to evaporate this quantity . . . . . | = 3,820 lbs. |
| Speed, per hour . . . . | = 11·4 miles. |

From these data may be investigated:—first, the evaporative power of the boiler; secondly, the duty of a cubic foot of water; and thirdly, the proportion which the work done, bears to the weight of the engine.

First:—255 cubic feet of water evaporated per hour, with 3,820 lbs of wood $= \frac{255 \times 62 \cdot 5}{3,820} = 4 \cdot 15$ lbs. of water per lb. of wood. The evaporative power of the engine would seem to be exceedingly perfect, inasmuch as the experiments of various chemists seem to give very nearly the same amount for stationary boilers. Thus Professor Johnson, in America, found that in a boiler, which evaporated 6·95 lbs. of water per lb. of Newcastle coal, 1 lb. of pine wood evaporated 4·69 lbs., from water at 212° Fahrenheit. The performance of the wood in this case, was quite in proportion to that of coke in English engines, and it seems to be greatly superior to the general return of the American engines, which are said to evaporate only 2 to 3 lbs. of water, per lb. of wood; this difference, however, may depend upon the quality of the wood. The above data give $\frac{255 \times 62 \cdot 5}{1,660} = 9 \cdot 6$ lbs. of water evaporated, per square foot of heating surface. The grate surface, as before mentioned, is 12·6 square feet, and consequently, the ratio of the heating surface to the grate surface, (1 : 130), is greater than that recommended by Mr. D. K. Clark,[1] (Assoc. Inst. C.E.,) for engines burning coke. His formulæ were these:—

$$C' = \cdot 0022 \left(\frac{h}{g}\right)^2 \qquad C = \cdot 0022 \frac{h^2}{g}$$

C′ being the economic evaporative power, in cubic feet per hour, per foot of fire grate; C, the total evaporative power, in cubic feet; $h$, the inside heating surface; and $g$, the grate area, in square feet. From 50 to 80, is the number expressing the usual ratio of the heating surface to the grate surface, in engines burning coke. The evaporation is 20·2 cubic feet, and the consumption of wood, upwards of 300lbs. per square foot of grate surface, per hour. These results are different again, from those given by coke-burning engines generally.

Secondly:—the constant resistance of the train, from the machinery, friction, &c., deduced from Mr. Gooch's experiments, is, on the English straight lines, about 8 lbs. per ton; and for the sharp Semmering curves, it has been assumed at about 12 lbs. per ton. The performance on the incline of 1 in 40, from Eichberg to Klamm, is rather better than that on the other portions of the line. Hence, with 165 tons, (engine and tender included,) at 11·4 miles per hour, the resistance per ton $= 12 + \frac{130}{171} + \frac{2,240}{40} = 68 \cdot 76$ lbs. Then $68 \cdot 76 \times 165 = 11,400$ is the total resistance,

[1] *Vide* Minutes of Proceedings Inst. C.E., 1853, vol. xii., pp. 382 *et seq.*

companies; and this plan was pursued on many lines in that country. The Southern Line, however, connecting Vienna with its seaport, Trieste, was probably too considerable an undertaking for any body of foreign shareholders at that time, as the crossing of such a mountain chain as the Semmering, was a novelty in European railways: the Government, therefore, undertook its construction. This Southern Railway crosses the Noric Alps at Semmering, and the Julian Alps at Adelsberg. It is divided into four sections, viz:—

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The length of tunnel is 2·55 miles; the depth of the shafts is about 600 feet; and the cost per yard forward, was £118. The gradients have curves of the minimum radius of 20 chains, which, it may be remarked, is a very much better minimum than that of the Semmering, which is only 9 chains.

The locomotive power employed for ascending the incline, consists of two engines of the same size, constructed by Messrs. Robert Stephenson and Co., of Newcastle, each carrying its own coke and water, and resting on four coupled wheels, moved by piston-rods, from outside cylinders. The diameter of the wheels is 3 feet 6 inches; that of the pistons is 14 inches, with a stroke of 22 inches. The two locomotives are bolted together, so that the fire-boxes are opposite to each other, and the driver stands on a common platform; when filled and loaded, the two engines weigh 55¼ tons; of this weight, the wheels nearest to the fire-box, carry about 7 tons each, and the others, about 5 tons each.

In fine weather, the locomotives will carry up about 100 tons, and in the worst weather, never less than 70 tons, at a speed of 15 miles per hour.

| | |
|---|---|
| Miles of passenger trains . . . . | 613·30 |
| Do. goods trains . . . . . . | 2,283·57 |
| Total . . . | 2,896·87 |

Weight in tons, of Trains lifted up.

| | |
|---|---|
| Passenger trains . . . . . . . | 6,467 tons |
| Goods trains . . . . . . . . . | 28,738 „ |
| Total . . . | 35,205 tons. |

| Dead weight carried ⅝ths of a mile: | in tons. |
|---|---|
| Not including the engine . . . . | 352,050 |
| Including the engine . . . . . | 585,150 |
| Coke consumed in ascending, including stoppages . . . . . . = | 195 tons. |

Consumption of coke per ton per mile, is—

| | |
|---|---|
| Not including engine . . | 1·94 lbs. |
| Including the engine . . | 1·16 „ |

The fuel consumed by the engine from the bottom to the top of the incline, 6 miles, with a gradient of 1 in 36, is 8·27 cwts.

In examining the results, it will be found, that 8·5 lbs. of water are evaporated per lb. of coke, and that 150 tons are raised up a gradient of 1 in 36, at the rate of 15 miles per hour.

The resistance is $10 + \frac{15^2}{171} + \frac{2,240}{36} = 74$ lbs. per ton, which, with the engine and tender, gives a power of $\frac{74 \times 150 \times 15 \times 88}{33,000}$ $= 444$ H. P., and without the engine, of $\frac{100 \times 74 \times 15 \times 88}{33,000}$ $= 295$ H. P.

Thus $\frac{295}{50} = 5{\cdot}9$ H.P., are exerted, per ton weight of the locomotive.

The consumption of coke per H. P. per hour, lifting goods, appears to be $\frac{1{\cdot}94 \times 15}{3} = 9{\cdot}7$ lbs. of coke raising 1,980,000 lbs., or 1 lb. of coke raising 204,000 lbs., 1 foot high.

It would be instructive to examine the results of the working of steep gradients, in England, by locomotives; but, in most instances, the expenses of working these comparatively short inclines, have been mixed up with the general mileage expenses, so as to render the comparison nearly impossible, and only in one instance, (as far as the Author is aware),—that of the Edinburgh and Glasgow Railway Incline,—has a complete comparison been made. Mr. William Fairbairn,[1] (M. Inst. C.E.,) gave, some years ago, an account of performances on rapid inclines, to show the possibility of a locomotive ascending a steep gradient; but as this question has been set at rest for some time, it only remains to investigate the most economical method of accomplishing it. The most important gradient, mentioned by Mr. Fairbairn, was that of the Accrington Incline, on the East Lancashire Railway, which has an average gradient of 1 in 42, for a length of 2 miles. A weight of 71·6 tons was drawn up an incline of 1 in 42, at the speed of 6·81 miles per hour, which gives a result of 74 H. P., and this, with an engine and tender weighing 43 tons, gives 1·7 H. P. exerted, per ton of engine and tender; a low result, when compared with that of the engines either at the Semmering, or the Giovi Inclines. In this instance, as in others, it has been found difficult, to separate the cost of working one mile of the incline, from the general mileage expenses.

Captain W. S. Moorsom, (M. Inst. C.E.,) in giving an account of the performance on the Lickey Incline, states, that 240 tons are drawn up a gradient of 1 in 37, at 6½ miles per hour, by a motor power weighing 67 tons, which represents 293 H. P., and 4·4 H. P. exerted, per ton of motor. It is to be regretted, that the work done by 1 lb. of coke, has not been stated.

[1] *Vide* Memoirs, Manchester Lit. and Phil. Soc., 1851, vol. ix. (Second Series), p. 149 *et seq.*

There remains now to be considered, the question of stationary and atmospheric engines.

The work performed on the Edinburgh and Glasgow Railway, with a wire-rope, on an incline of 1 in 42, may be estimated from the following data:—

The length of the incline is 1¼ mile, with a gradient of 1 in 42.

The rope was put on in March 1853, and taken off in January 1855, the trial having lasted twenty-three months. The distance run whilst lifting trains, was 21,250½ miles; the number of ascents was 14,167; and the number of carriages, &c., carried up the incline, amounted to 205,181: the average gross weight per train, was 86 tons.

The prime cost of the rope was £1,094; the cost per mile run with rope, was 12·38*d.*, or 24 per cent.; the total cost of working the line, including the rope, = 50·299*d.* per mile, which is divided into—

| | *d.* |
|---|---|
| Rope, per mile . . . . . . | 12·380 |
| Coal „ . . . . . . . | 11·195 |
| Engine-driver, Breaksman, &c. . . | 26·724 |
| Total . . . . | 50·299 |

The quantity of coal consumed per mile, to lift 86 tons, is 527 lbs., and the cost of coal per mile, 11·195*d.*

The friction of the rope is stated by Mr. Gordon, at one-twentieth of its weight.

From the data of 86 tons, drawn up an incline of 1 in 42, at the speed of 15 miles an hour, there results, $8 + \frac{15^2}{171} + \frac{2,240}{42} = 62$ lbs. resistance. Then, $\frac{86 \times 62 \times 15 \times 88}{33,000} = 426$ H. P. exerted, and besides this, 88 H. P. are required to lift the rope at 15 miles an hour, and 1 lb. of coal raises 46,000 lbs., 1 foot high, neglecting friction of machinery and of rope.

Mr. Paton says, this incline, of 1 in 42, was at first worked by a stationary engine with a hempen rope; but as it was found to be very much affected by damp, locomotives were tried, and answered very well. A wet condition of the rails, however, caused serious loss of adhesion. The locomotive engines used, had cylinders of 16 inches diameter, and 25 inches stroke, with wheels, 4 feet 4½ inches in diameter, and took up with ease, loads of 80 to 100 tons. They were ultimately abandoned, and a stationary engine was again employed to work a wire-rope.

The rope weighs 10 lbs. per yard, and is 4⅝ inches in circumference, and on several occasions, there have been as many as thirty loaded carriages on each train, and goods trains of 120 tons,

every day, yet no accident, or detention, occurred, during the period of trial.

The total cost of working the Glasgow Incline for one year, was £734 18*s.* 1*d.*, when the rope was used, and £3,204 16*s.* 10*d.*, when locomotives were used, giving a difference of £2,460 18*s.* 9*d.*, in favour of the wire-rope system. It does not, however, appear, that the locomotives employed, were well adapted for the traffic, and indeed, it seems to be almost generally believed, that for short distances, locomotive traffic should not be interrupted; but the superior economy and rapidity of transit, in the case of the Glasgow Incline, seems to point out the propriety of adopting some such means, in the ascent of long Alpine gradients of 10, or 12 miles of such inclinations as 1 in 40, where ropes of 6 miles long might be used. The system of ropes would admit of the adoption of gradients of 1 in 25, or 1 in 20, in which case, enormous expenses in viaducts, &c., would be avoided.

The following account of the atmospheric system, is derived from M. Flachat of Paris. The incline is that on the St. Germains Railway, of an average gradient of 1 in 43; but at one part, it is 1 in 33 for the distance of 50 chains, and the total length of the plane is 1·46 mile.

| | |
|---|---|
| The number of miles run, lifting trains, was | 2,125 |
| And the number of ascents . . . . | 1,413 |
| The total number of carriages lifted up . | 10,463 |
| And the weight of these . . . . . | 73,241 tons. |
| The average weight per train . . . | 51·8 „ |

The total cost of working the stationary engine, including engine-man, coal, water, oil, and tallow, during the period from 2nd January to 18th August 1855, was £612 10*s.*, from which is obtained, the cost per mile of ascent = 5*s.* 9½*d.*, for lifting 51·8 tons. The cost of a ton of coals was 24f. 50c. The expenses for the maintenance of the valve and tube, are not included in this statement, and may be calculated at £400 per annum. Commercially, this gives 454 lbs. of coal, raising 51·8 tons, 1 mile of 1 in 43, or 123 feet high; or 1 lb. coal raises 31,400 lbs., 1 foot high, not taking speed into account.

This is to be compared, with the superior performance of the stationary steam engine, viz., 46,000 lbs. raised 1 foot high, by 1 lb. of slack, costing about 4 shillings per ton. The atmospheric system seems, indeed, to be almost universally condemned, from the impossibility of augmenting its power in emergencies.

From the foregoing duties, the following results are derived:—

The Semmering locomotives:—

| | | |
|---|---|---|
| Total power exerted . . | = | 380 H. P. |
| Power available to lift trains . | = | 285 „ |
| Power per ton of motor . . | = | 5·2 „ |

Economically, 1 lb. of wood raises—
136,000 lbs., 1 foot high,
or 82,208 lbs., „ leaving speed out of consideration.

The Giovi locomotive :—

| | | |
|---|---|---|
| Total power exerted . . | = 444 | H. P. |
| Power available to lift trains . | = 295 | „ |
| Power per ton of motor . . | = 5·9 | „ |

Economically, 1 lb. of coke raises—
204,000 lbs., 1 foot high,
or 169,568 „ „ leaving speed out of consideration.

The East Lancashire locomotive :—

| | | |
|---|---|---|
| Power available to lift trains . | = 74 | H. P. |
| Power per ton of motor . . | = 1·7 | „ |

The Hunt's Bank locomotive :—

| | | |
|---|---|---|
| Power available to lift trains . | = 131 | H. P. |
| Power per ton of motor . . . | = 5·4 | „ |

The Glasgow Incline stationary engine :—

| | | |
|---|---|---|
| Power available to lift trains . | = 452 | H. P. |

Economically, 1 lb. of coal raises—
45,700 lbs. 1 foot high, leaving speed out of consideration.

The St. Germains Atmospheric Railway :—
Economically, 1 lb. of coal raises 31,136 lbs., 1 foot high.

As regards the use of locomotives for working inclines, the construction of the Giovi and Semmering engines points out, that attention to one, or two principles will insure good results.

1st. There must be heating surface and grate area in the boiler, sufficient to generate the steam requisite for the necessary horse power.

2nd. The cylinders must be large enough, and the diameter of the wheels small enough, in proportion to the crank, to enable the pressure of steam in the cylinder to overcome the resistance of the load at the rails, on steep gradients.

3rd. The load on the driving-wheels must be sufficient, to insure their adhesion; this load, in both the Semmering and Giovi locomotives, varies from eight to ten times the resistance at the rails. The limit to locomotive performances is assigned, by the smallness of the wheels diminishing the speed; and by the load on these wheels reaching a point, at which the rails become seriously damaged by it.

As it would be very desirable, to arrive at some conclusion, as to

the best and most economical method of crossing mountain chains by railways, perhaps it may be useful to offer a short résumé of the results of the four examples of construction, given in this Paper.

The performances of the locomotives on the Semmering, and on the Giovi Inclines, seem to be almost equally good, taking into consideration, that on the former, wood was burnt, and on the latter, coke.

There seems to be some little advantage in the adoption of two engines to do the work of one, as the weight on the rails need not perhaps be so great, at any one point, in the former case, and consequently, the permanent way may be made at less expense.

There is great difficulty in obtaining experiments on a sufficient scale, for establishing a correct comparison between the expenses of the stationary engine with a rope, and the locomotive engine, on steep inclines: on light gradients, the locomotive often proves superior, on account of the large horse power required to move the rope. This power, however, would seem to remain almost a constant, for a given length, and not to be affected by the sharpness of the incline, since the rope is made endless, and the weight of one half balances that of the other, so that on very steep inclines, when the power of the locomotive becomes less efficient, and an enormous weight is required to be put on the wheels, to prevent slipping, the rope is only an augmentation of the load required to be raised.

The only complete comparison of the working by ropes and by stationary engines, with the working by locomotives, was on the Cowlairs Incline; but, even here, the data are very unsatisfactory, as the locomotives used, do not appear to have been so well constructed, as those on the Giovi, or the Semmering. The difference in performance can, however, scarcely have been so great, as to invalidate the result of the superior economy of the stationary engines. In the absence of further direct experiment than that made by Mr. Paton, the duty of 1 lb. of coke on the Giovi engine,—169,000 lbs. useful load raised 1 foot high,—may be compared with 45,700 lbs.,—that of 1 lb. of inferior coal, or slack, on the Cowlairs Incline. The result is, that the duty of the former is 3·4 times that of the latter, or nearly the proportion of the heating effect of the fuel. One advantage of the use of ropes for steep inclines is, that the water power of the district may be used as an auxiliary, and this power is often ample in mountainous countries, except in winter.

As to the atmospheric system, the experiments quoted, seem to prove its great inferiority in economy to the others; although M. Flachat's experiments show the high result of 8·9 lbs. of water evaporated, per lb. of coal.

In conclusion, although the evidence seems somewhat in favour of the adoption of steeper inclines, worked by ropes, in place of the present gradients of the Semmering and the Giovi, worked by locomotives, there are so many obstacles to a clear view of this question, that this Paper rather invites discussion, than asserts the advantage of either system.

The Paper is illustrated by diagrams of the Semmering and the Giovi Inclines, and of the 'Engerth' locomotive.

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[CAPTAIN W. S. MOORSOM

Captain W. S. Moorsom said, he believed, that the Lickey Incline on the Birmingham and Gloucester Railway and the Dainton Incline on the South Devon, were the only two in Great Britain, which were at all important with regard to large, or speedy traffic, as they were in the middle of lines, over which express trains passed without necessarily stopping. It was difficult to obtain from those who had the management of the working of railways, precise data for instituting a comparison with those given in the Paper. This chiefly arose from the accounts being kept for commercial purposes only, and thus giving the general results of the working of the entire line, without reference to such portions as were now under consideration. From such data, however, as by favour of the managers, he had been able to collect, and from his own experience on the subject, he would endeavour, as far as was practicable, to establish a comparison. On the Semmering Incline, the average load per train was given as $165\frac{1}{4}$ tons, which was moved at a speed of $11\frac{1}{4}$ miles per hour, up an incline of 1 in 40, with a consumption of wood of 340 lbs. to the mile: the pull of the engine might, therefore, be taken at 10,300 lbs. On the Giovi Incline, which was 1 in 36, the greatest load, of 150 tons, including the two engines, was moved at a speed of 15 miles per hour; the coke used was 174 lbs. per mile, and the pull of the engine, under those circumstances, would appear to be 10,600 lbs.: there was thus, a rather steeper incline and a little more force exerted by the engine, with a greater speed, than in the case of the Semmering Incline. The Lickey Incline was 1 in 37, and two engines were employed,—the bank engine of 35 tons, and an ordinary goods engine of 32 tons. Taking the average load of goods trains, as furnished by Mr. Kirtley, to be 307 tons, this was the weight which might be assumed to be moved up that gradient, at an average speed of $6\frac{1}{2}$ miles per hour, with a consumption of coke, of 80 lbs. per mile. The question of consumption of coke was subject to some difficulty; the amount he had given, was an average upon the total quantity consumed by the bank engines, as no separate account was kept with regard to this incline alone. It resulted from these conditions, that the two engines together exerted a force of 21,800 lbs., or nearly double that on the Giovi and Semmering Inclines, while the speed was about one-half less. It appeared, from statements, furnished by Mr. Gooch, that on the Dainton Incline of the South Devon Railway, the average load of a goods train, including engines, was 215 tons, which was moved at the rate of $11\frac{1}{2}$ miles per hour. He confessed, that from his own observation, he should not have thought the speed was so great. The gradient was 1 in 45, and the quantity of coke consumed, was $58\frac{1}{2}$ lbs. per mile. This, again, was the average consumption per train mile, but on

that particular portion of the line, he believed it would be, at least, 50 per cent. more. In this case, the pull of the engine was about 12,500 lbs.

It was stated in the Paper, that the Austrian Engineers, in considering the weight to be given to the engine for working the inclines, thought, that adhesion could not be obtained, without a weight on the wheel, equal to eight times the force of the pull of the engine. He ventured to say, that it was practicable to ascend even greater inclines, with a weight equal to only five times the drag of the engine. He was endeavouring, at the present time, to get a trial under these conditions, and he hoped, before long, to be able to present it as an accomplished fact, instead of a prospective idea. Whilst upon the subject of adhesion, he would mention, that on an incline of his own construction, he had sometimes seen the train brought to a stand, and on examining the sand-box of the engine, instead of sand he had found in it only stones, and clay: this naturally accounted for the difficulty experienced in working the incline, and he believed, that the difficulties experienced on other inclines, were often due to similar carelessness.

It was also stated, that none of the engines employed in England, would move the loads at the same rate, as those upon the Semmering Incline: but he could not admit, that those engines showed any improvement upon the practice of this country, for the last fifteen years. He believed, that as early as the year 1845, a peculiarly-powerful engine was working on the Lickey Incline, and he concluded, that it was one of those of which Mr. Kirtley had given an account. Now if it was correct, that 307 tons could be moved up that gradient of 1 in 37, at the rate of 6½ miles an hour, with one large and one small engine, it followed, that one alone would be quite able to haul the 165¼ tons spoken of as the Semmering performance, at an equal speed of 11 miles per hour. One of those engines had been in the habit of drawing up fifty loaded waggons at a time, weighing, perhaps, 250 tons. On the Dainton Incline, lighter trains of 79, or 80 tons, were moved at the rate of 17 miles an hour; the pull of the single engine which did that work, was about 4,600 lbs., and the consumption of coke, (taken, as in the other cases, at the average per mile, on the whole line,) was only 24 lbs. per mile.

Mr. Hawkshaw, V.P., was anxious to correct a statement, which might have the effect of misleading those who were unacquainted with the railway system of this country. It had been asserted, that the Lickey and the Dainton were the only inclines worthy of notice: but such was not the case. There were a great number of inclines on the English and Scotch lines, and they were increasing every year; for railways were continually in course of construction through hilly districts, which were formerly regarded

as impracticable. Even before the construction of the South Devon Line, there were numerous inclines, which were worked with a large passenger traffic. Halifax, for instance, had an incline of 1 in 44, and thirteen years ago, twenty-two passenger trains, together with heavy goods trains, were daily, without difficulty, conveyed over it. The change in the views of Engineers on this subject, had been very great. He remembered the time, when a gradient of 1 in 100 was thought to be the utmost that ought to be ventured upon; and that, with 1 in 50, locomotives must be put aside, and ropes must be employed. The incline on the North-Western Railway, from Camden Town to Euston Station, was for a long period, worked by a rope, which was considered the only practicable mode, although the rise did not average more than 1 in 66. The result of experience had been to discard the rope and trust wholly to locomotive power. There was scarcely a portion of railway in England over which more traffic passed, than the incline at Hunt's Bank, on the Lancashire and Yorkshire Line, where the gradients were 1 in 50 and 1 in 49, yet it was daily accomplished without stoppage, or accident. Another incline, also under his charge, where rope traction was, until very recently, employed, was that at the approach to Oldham, a town 8 miles from Manchester, with 120,000 inhabitants: that incline was 1 in 27 for $\frac{3}{4}$ mile. To avoid it, another line was proposed between Manchester and Oldham, with a gradient of 1 in 60, but the Engineer declined to support even that gradient, unless it were worked with a rope. The result was, that the incline of 1 in 27, was maintained, but, two years ago, it was found, that the rope was of no advantage, and trains now ran up this incline every half-hour, by locomotive power alone. The trains, it was true, were not heavy, generally consisting of six, or seven carriages, and the goods trains, of eight, or nine trucks. He might add, with reference to the inclines in Lancashire and Yorkshire, that the engines were not specially constructed for working them, but the ordinary engines were, generally speaking, quite equal to the duty. It was not necessary to enter into a comparison of the work performed on different inclines, for it was clear, within certain limits, that engines could be made powerful and heavy enough, to take any weight up any incline, and the proper weight and power to be employed must be left to the prudence of the Engineers. He applied this remark to the opinion which had been expressed, that the weight might be reduced from eight times, to five times the drag of the engine; but this was not a question of engineering skill, for the degree of adhesion obtained, very much depended upon the state of the weather. A long list could be given of gradients similar to those he had mentioned: at Bradford, and again at Leeds, he had made inclines of 1 in 50. Steep inclines

were, therefore, no novelty, in railway engineering, nor were the performances cited, greater than those which had been accomplished for years past, in this country.

CAPTAIN W. S. MOORSOM explained, that in speaking of the Lickey and Dainton Inclines as the only ones worth mentioning, he did not mean to imply, that there were no others on which a large traffic was worked, (although fifteen years ago, there were, comparatively speaking, no large traffics); but he meant, that those inclines were, and still remained, almost the only ones which presented any very heavy gradients, and which, being situated in the middle of the course of the lines, had to be worked on different conditions to the terminal inclines at Oldham, Halifax, &c.

As to the question of priority, he believed, that anterior to the working of the Lickey Incline, in 1839-40, there was no other of any importance, on which locomotives conveying trains, freely ascended. He claimed no scientific merit for the suggestion of reducing the weight to five times the power of the engine: but he could not admit, that adhesion was a question of weather. Whatever might be the state of the weather, and the state of the rails, the above proportion was, in his opinion, quite sufficient to enable the engine to work up an incline.

Mr. HAWKSHAW, V.P., observed, that the Hunt's Bank and Halifax Inclines were originally terminal inclines, although they were now no longer so. But he did not consider that fact very material, for it did not affect the power which the engine was called upon to exert.

Mr. VIGNOLES said, he was among the first to advocate the adoption of steeper gradients. Being well acquainted with the Semmering Incline, he would call attention to the sharp curves on that line, of not more than 10 chains radius, with a gradient of only 1 in 42, which must materially influence the working of the engines, at even a moderate speed, and require an increase of power. But the most important question for consideration, and upon which he had stated his opinion to the Austrian Government, was, whether such heavy engines as those of the 'Engerth' construction, could be worked as conveniently and economically as a number of smaller engines coupled together, or disposed in different parts of the train. He was convinced, that the latter system, which was the one adopted in England, and on the Giovi Incline in Piedmont, was preferable to the Austrian plan, both in point of convenience, economy, and regularity. It was now about twelve years ago, that a steep gradient was adopted in Bavaria, and this was the first introduction of such inclines on the Continent: in that instance, the curves were easier than those on the Semmering, but the gradient was 1 in 40, which, he conceived, could be easily worked by locomotive power. As far back as 1833, he continually

ran up the St. Helen's Incline, which was then 1 in 30, with an engine and carriages, without having the rope attached.

With reference to adhesion, from the experiments he had made, he had come to the conclusion, that it could not be depended upon in all states of the weather, at more than one-fifteenth of the weight; and he had found, that the adhesive power decreased in the ratio of the sine of the angle of inclination of the plane.

Mr. JEE was of opinion, that lighter engines were preferable, both as regarded economy in the engine and train, and in the wear and tear of the rails. The following were the results of some experiments on the working of an engine, the 'Isabel the Second,' constructed by Messrs. Dodds and Son of Rotherham, for the Santander and Alar Railway in Spain, of which he was the Engineer.

The engine had inside cylinders, and four wheels coupled; the diameter of the cylinders was 14¼ inches; the length of stroke, 20 inches; the diameter of the wheels, 4 feet 6 inches; and the blast pipe, 3¾ inches in diameter. There were 830 square feet of heating surface; 72 square feet in the fire box, and 758 square feet in the tubes. The pressure in the boiler was 90 lbs. per square inch; the weight of the engine in working order was 19 tons 15 cwt.; and the weight of the tender, when full, was 10½ tons.

On the 30th of April, 1853, the engine was started upon an inclined plane of 1 in 27, at Sheffield, and drew up 23½ tons, (exclusive of tender,) at a velocity of about 2½ miles per hour: the length of the plane was about 300 yards.

On the 25th of June, 1853, a first experiment was made on the Lickey Incline, of which the gradient was 1 in 37; the day was foggy, with drizzling rain. The engine started from the bottom of the incline, with six waggons, of which the gross weight was 45 tons, 13 cwt., 3 qrs., and the following were the times of passing each distance-post, placed at one furlong apart:—

| Miles. | Furlongs. | h. | m. | s. | Miles. | Furlongs. | h. | m. | s. |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 12 | 12 | 30 | 1 | 1 | 12 | 21 | 19 |
| 0 | 1 | 12 | 14 | 0 | 1 | 2 | 12 | 22 | 0 |
| 0 | 2 | 12 | 15 | 24 | 1 | 3 | 12 | 22 | 41 |
| 0 | 3 | 12 | 16 | 20 | 1 | 4 | 12 | 23 | 21 |
| 0 | 4 | 12 | 17 | 20 | 1 | 5 | 12 | 24 | 2 |
| 0 | 5 | 12 | 18 | 16 | 1 | 6 | 12 | 24 | 47 |
| 0 | 6 | 12 | 19 | 6 | 1 | 7 | 12 | 25 | 32 |
| 0 | 7 | 12 | 19 | 54 | 2 | 0 | 12 | 26 | 26 |
| 1 | 0 | 12 | 20 | 37 | | | | | |

The mean velocity, after the load was fairly in motion, was, therefore, about 10 miles per hour.

A second experiment was made on the same day, the rain still

falling, as before. The engine started from the bottom of the incline, with four waggons, of which the gross weight was 29 tons, 4 cwts., 1 qr., and passed each distance-post at the following times :—

| Miles. | Furlongs. | h. | m. | s. | Miles. | Furlongs. | h. | m. | s. |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 33 | 28 | 1 | 1 | 1 | 37 | 17 |
| 0 | 1 | 1 | 34 | 14 | 1 | 2 | 1 | 37 | 41 |
| 0 | 2 | 1 | 34 | 44 | 1 | 3 | 1 | 38 | 6 |
| 0 | 3 | 1 | 35 | 3 | 1 | 4 | 1 | 38 | 30 |
| 0 | 4 | 1 | 35 | 26 | 1 | 5 | 1 | 38 | 56 |
| 0 | 5 | 1 | 35 | 49 | 1 | 6 | 1 | 39 | 19 |
| 0 | 6 | 1 | 36 | 11 | 1 | 7 | 1 | 39 | 45 |
| 0 | 7 | 1 | 36 | 32 | 2 | 0 | 1 | 40 | 15 |
| 1 | 0 | 1 | 36 | 55 | | | | | |

The mean velocity, after getting into motion, was, therefore, about 18½ miles per hour.

Mr. E. Woods said, he doubted whether the performance of the engines could be fairly taken as the basis of comparison, in the working of inclines, as any difference in the wind, a slippery condition of the rails, and various other circumstances would have a material influence on the result. From all his experiments on the subject, he had never been able to draw any general conclusions at all satisfactory, unless he took an average of a great number, made in different states of the weather, or unless he tried special experiments, under similar loads, in the same state of ground and of weather. The Paper did not give any very explicit statement as to the conditions under which the experiments were tried: and it appeared to him, that the results of the Semmering Incline had been taken from specific experiments, whilst on the Giovi Incline, they were only an average; but in any case, the engines employed on English inclines, were quite as efficient, relatively to their weight, as those on the continent. It was evident, that the load that could be hauled by an engine, was in proportion to the weight upon the driving-wheels. As to the adhesive power, one-fourth, or one-fifth of the weight might be available in dry weather, but under other circumstances, the adhesion was reduced to one-tenth or one-fifteenth, and he did not think, that on the average, it could be depended upon at more than an eighth. He agreed in the preference accorded to several small engines over one large engine, as the latter was, necessarily, more complex in construction, and consequently, more difficult to keep in order. It had been supposed, however, that the one large engine would work more effectually; but this problem had been solved on the Madeley Incline of the London and North-Western Railway. Two of the Crewe goods engines, of equal power, and with a load of 280 tons each,

were each taken separately, and afterwards conjointly, up inclines of 1 in 330, 1 in 255, and 1 in 177 between Crewe and Whitmore, where the length was $7\frac{5}{8}$ miles, and their speed and pressure carefully compared. 230 The result was, that the double train was drawn up, by the two engines coupled together, in the average time that each had taken up half the load separately. The engines had 13 tons on the driving-wheels, which were 5 feet in diameter; that of the cylinders was 15 inches, with a stroke of 20 inches; the heating surface was 650 square feet, and the grate surface, $10\frac{1}{2}$ square feet.

He thought there must be some error with regard to the great difference given in the Paper, of the cost of working the incline of the Edinburgh and Glasgow Railway, by a stationary engine, or by locomotive power: he could hardly conceive, that the latter could increase the expense by £2,460 per year. He had some experience in stationary engines at Edge Hill, Liverpool, where there were three inclines,—two for the goods traffic to the North Dock, and the other for the passenger traffic into the town. These 110 inclines were, respectively, 1 in 48, 1 in 90, and 1 in 56, and they 94 were each about $1\frac{1}{2}$ mile in length. 56 These inclines were still worked by ropes and stationary engines, because, being situated in tunnels, it was found, that the condensation of the steam on the rails, when locomotives were tried, so lessened the adhesion, that in these particular cases, it almost amounted to an impossibility of carrying out that system. The cost of working 70,551 miles in 1852, was £2,064, or 8 pence per mile, reckoning the mileage both up and down.

Mr. W. Fairbairn, through the Secretary, stated, that on the Oldham Incline, $1\frac{1}{2}$ mile in length, with a gradient of 1 in 27, a tank engine weighing about 27 tons, constructed by Messrs. W. Fairbairn and Sons, drew at the rate of 15 miles per hour, a train of nine loaded carriages weighing 50 tons.

The dimensions of the engine were,—

| | Feet. | Inches. | |
|---|---|---|---|
| Leading-wheels . . . . | 3 | 6 | diameter. |
| Driving-wheels (four coupled) . | 5 | 0 | „ |
| Cylinders . . . . . | 1 | 3 | „ |
| Length of stroke . . . . | 2 | 0 | „ |

It was extremely difficult to establish any useful comparison between the working of any given inclines, in consequence of the dissimilarity of conditions, of local circumstances, and of the different modes of keeping the accounts of the expenses.

Mr. Nicholas Wood thought it very important to ascertain the precise amount of adhesion. The friction of iron upon iron was about one-fourth, but with wheels rolling upon iron rails, the

60 ft

adhesion, under certain circumstances, fell to one-tenth, or one-fifteenth: his own experience had given one-eighth of the weight, as very near the average, and he did not certainly think it would be safe to trust to one-fifth. That point being admitted, the rest was a question of the advantageous employment of the steam, and the construction of the engines themselves. He was certainly struck with the difference of cost stated, between locomotive power and the stationary engine, on the Edinburgh and Glasgow Line. Although the cost of locomotive traction might be increased at some particular terminal inclines, yet he had no doubt, that, on the whole, the use of that power would in such cases, prove to be generally the most economical.

Mr. Bidder, V.P., did not understand from the Paper, that the Author recommended the particular class of engine, employed on the Semmering line: he regarded it as a fair and frank statement of certain facts, which it was desirable to record.

It must be evident, that the plan of working the Giovi Incline by two of Messrs. R. Stephenson and Company's coupled engines, was very much better and more economical, than the system of using such enormously-heavy engines, as those constructed from the designs of Mr. Engerth, for working the Semmering Incline. It was decidedly more economical, as well as more convenient, to be able to work an incline, by merely coupling together the ordinary engines, than to have ponderous machines constructed expressly for the duty of ascending steep gradients, and unfit for working the other portions of the line. Besides, the injury to the permanent way, by such enormously-heavy engines, must be considered, when comparing their duty with that of two engines, whose weight was so much better distributed. A better adhesion of all the wheels was obtained, whilst there was thus no necessity for spur-wheels, which were always attended with risk and inconvenience.

With respect to adhesion, it was impossible to lay down a law of one-fifth, or one-eighth. Circumstances of climate would always affect adhesion; in the fine, dry cold climate of Norway, inclines could be advantageously worked, whereas in a London fog, or even with the ordinary moisture of a dewy night, the adhesion would be materially impaired. In some states of the atmosphere in England, there had not been an adhesion of even one-twentieth; but the most extraordinary difficulty he had witnessed, was that attending a shower of sleet, which froze on the rails as it fell.

Ropes had been generally superseded by locomotives, but it should not be rashly decided to abandon them entirely, as there were situations where steep terminal gradients might still be advantageously worked by them; whereas it would be preferable, or even almost indispensable, to work the inclines in the course of a line, by locomotive power. The relative advantage of the two systems

depended entirely upon the peculiar circumstances of the case, and the great difference between current and terminal inclines must never be lost sight of.

An interesting part of the subject, was the consumption of fuel and the amount of water converted into steam, relatively to the work performed. On the Semmering Incline, he found, that the consumption of wood was at the rate of about 3,800 lbs. per hour, or 340 lbs. per mile, equal to 170 lbs. of coke. The consumption was thus equal to about 1,700 lbs. of coke per hour: while in England, the express trains, running with a load of 170 tons, at a speed of 50 or 60 miles, did not consume more than 1,300 lbs., or 1,400 lbs. per hour. The question of relative consumption of fuel and evaporation of water, required further investigation, and all well-authenticated results should be laid before the Institution.

Mr. Crampton, through the Secretary, said, that in May 1850, he had had several communications with the Austrian Government upon the subject of the Semmering Incline, and he had recommended the adoption of the system of coupling two locomotives together, and working them by one engineer and a stoker. With respect to the introduction of the system, which was now so successfully employed on the Giovi Incline, he would mention, that at Turin, in January 1851, Mr. Maus, the Engineer, had showed him his plans for working it by a rope, when Mr. Crampton advised him to adopt the method he had previously recommended to the Austrian authorities, and which he had already proposed, so far back as 1846. The arrangement was, moreover, published before 1850.

Mr. W. Weallens, through the Secretary, gave the following account of the performance, during the month of June 1854, of the Double Tank-Locomotives working on the Giovi Incline. The mean performance was taken from an average of goods and passenger trains.

| | | |
|---|---|---|
| Total number of miles run . . . . | | 2896·87 miles. |
| Do. weight of trains, in tons . . . . | | 35205 tons. |
| Do. consumption of coke . . . . . | | 195 „ |
| Do. consumed in lighting fires . | 26·8 tons | 44·7 „ |
| Do. do., when standing . . | 17·9 „ | |
| Do. consumption in working the trains . | | 150·3 „ |
| No. of trips in the month (ascending) . . | | 444 |
| Average weight of train . | 79·29 tons | |
| Weight of one double Engine | 55·25 „ | |
| Total weight of train . . . . . | | 134·54 tons. |
| Mean speed of goods and passenger trains . | | 11 miles per hour. |

| | |
|---|---|
| Length of Incline . . . . . . | 6·5 miles. |
| Coke consumed in each trip . . . | 760·77 lbs. |
| Do. do., per ton in each trip . . . | 5·6 " |
| Do. do., per ton per mile, including engine | ·86 " |
| Do. do., not including engine . . . | 1·5 " |
| Mean resistance (according to Mr. D. K. Clark's formula) due to 11 miles per hour, and incline of 1 in 36 . . . | 76 lbs. per ton. |

$$\frac{134{\cdot}5 \times 76 \times 968}{33000} = 300 \text{ H. P., including engine in load,}$$

and $$\frac{79{\cdot}29 \times 76 \times 968}{33000} = 177 \text{ H. P., not including engine.}$$

$$\frac{177}{55\frac{1}{4}} = 3{\cdot}2 \text{ H. P. per ton of motor.}$$

$$\frac{79{\cdot}29 \times 1{\cdot}5 \times 11}{177} = 7{\cdot}4 \text{ lbs. of coke per H. P. per hour,}$$

and $$\frac{33000 \times 60}{7{\cdot}4} = 267{,}716 \text{ lbs. raised 1 foot high per hour by 1 lb. of coke.}$$

Captain W. S. Moorsom remarked, that rapid speeds, with light trains, upon flat gradients, amounted to very much the same as slow speeds, with heavy weights, upon an incline. The engine would require the same consumption of fuel, as it was really only doing the same amount of work in a different form, and the same amount of horse power was necessary to perform it.

Mr. Drysdale believed, that the horse power would be found to be nearly the same in the two cases. Upon the Semmering Incline, it was very nearly that required by the express trains, and the quantity of water per horse power would be the same. With regard to adhesion, recourse should not be had to *à priori* arguments, but facts alone should be relied on, and these would be found to give the power of adhesion, at from one-eighth to one-tenth of the weight on the wheels. It was a valuable remark, that the adhesion was inversely in proportion to the sine of the angle of inclination. It was of great importance, that the question of the comparative economy of working inclines by locomotives, or by ropes, should be clearly investigated. It was a doubtful question, whether locomotives would be able to surmount an inclination of 1 in 20, or 1 in 17; and in the Alpine passes and on the Spanish lines, where so many mountain chains had to be passed, it might be desirable to consider the application of the rope traction as a matter of economy, both in construction and working. In those districts, if such gradients could be worked with facility, the construction of many costly viaducts and other structures might be avoided; and, of

course, the less the expense necessary to be incurred in the formation of any railway, the greater chance was there of its being satisfactorily executed. Upon this subject, he had only given the facts as he found them. The cost of the locomotive, as compared with the stationary engine traction, on the Edinburgh and Glasgow Incline, was taken from the published statements of the Company. The increase in cost might be accounted for, in some measure, by the difference between the price of coke in Scotland, and the price of the coals used for the stationary engine, which latter were, he believed, obtained for 4 shillings per ton.